(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 0 899 588 A2

(12) EUROPEAN PATENT APPLICATION

(43) Date of publication:
03.03.1999 Bulletin 1999/09

(51) Int Cl.6: G01T 1/20

(21) Application number: 98306933.7

(22) Date of filing: 28.08.1998

(84) Designated Contracting States:
AT BE CH CY DE DK ES FI FR GB GR IE IT LI LU MC NL PT SE
Designated Extension States:
AL LT LV MK RO SI

(30) Priority: 29.08.1997 US 921234

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(54) Scintillation detection

(57) A radiation detector includes wavelength-shifting optical fibres which are selected and arranged to capture a greater percentage of visible photons through the use of two or more different colour stages of wavelength-shifting fibres. A primary set of optical fibres (50) contains a first wavelength-shifting optical fibre tuned to absorb photons emitted by the detector crystal (12) and to re-emit photons at a longer wavelength. At least some of the re-emitted photons from the primary set of optical fibres are captured and transmitted down the first wavelength-shifting optical fibre. A secondary set of optical fibres (54) contains a second wavelength-shifting optical fibre tuned to absorb photons emitted by the primary set of optical fibres and to re-emit photons at a still lower frequency. In this way at least some of the photons emitted by the primary set of optical fibres and not transmitted down the first optical fibre are captured and transmitted down the secondary optical fibre. An electro-optical device such as a PMT or photodiode is positioned to detect photons received from at least one end of the first or second wavelength-shifting optical fibres and to generate an electrical signal in response.

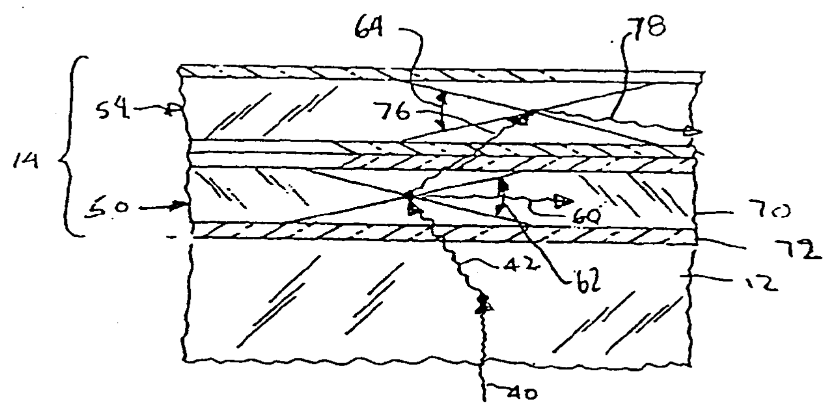

FIG. 5

Description

[0001] The present invention relates to a scintillation detector and to a method for use of a scintillation detector. and in particular to a scintillation detector and method which utilize wavelength-shifting optical fibres and to cameras using such a detector.

[0002] Scintillation detectors are used in medicine to detect radiation emitted from a patient as a result of an internally administered radiopharmaceutical or emitted from a source external to the patient. Such detectors are used in many modern medical imaging techniques including computed tomography (CT), single photon emission computed tomography (SPECT), and positron emission tomography (PET). Scintillation detectors include a scintillator usually a scintillation crystal, and one or more photomultiplier tubes (PMTs) or other photosensors to locate the origin and determine the energy of a gamma ray or other incident radiation. In the simplest case when a gamma ray interacts with a scintillation crystal. the gamma ray ejects an energetic electron. If the gamma ray is completely absorbed by a photoelectric interaction the ejected electron is called a photoelectron. As the ejected electron returns to its rest energy level. one or more photons are emitted. For typical scintillation crystals the emitted photons are in the visible spectrum (light) Medical imaging systems create an image by recording the location of each flash of visible light in the scintillation crystal and then calculating the location and shape of the source of gamma rays that generated the flashes which may be a tumour or other body part of a patient who has been treated with a radiopharmaceutical

[0003] The resolution of a scintillation detector can be improved by the use of wavelength-shifting optical fibres to capture photons emitted by the scintillation crystal. These fibres can be laid in orthogonal layers of fibres. A PMT connected to the end of each fibre provides a signal when a visible-light photon is captured and propagated through the fibre to the PMT. When the PMTs connected to an orthogonal pair of fibres record photons at the same time. the source of the gamma ray is determined to be at the intersection of the two fibres. One such system is shown in U.S. Patent 5,600,144. While using wavelength-shifting optical fibres can improve the image resolution of a detector, room for improvement in the intrinsic spatial resolution of the detector (Δx) and the intrinsic energy resolution of the detector ($\Delta E/E$) remains.

[0004] In this specification and the accompanying claims the term "radiation" is meant to include any form of high-energy rays. For instance, electromagnetic radiation such as gamma radiation (high energy electromagnetic photons), alpha radiation (helium nuclei), beta radiation (high energy electron radiation) and x-rays. Gamma rays are used throughout as exemplary because they are widely used in medical imaging.

[0005] When a gamma ray interacts with a scintillation crystal, the crystal gives off light (photons in the visible spectrum) equally in all directions (isotropically). These photons primarily have a wavelength, λ_0, which is a characteristic of the crystal material, and particularly, is influenced by dopant chemicals added to the crystal to control the crystal's scintillation properties.

[0006] Photons emitted by the scintillation crystal at a wavelength, λ_0, may strike one of the wavelength-shifting fibres which are adjacent the crystal. If the incoming photons strike the fibre at an angle of incidence which is greater than some critical angle, the photons will be reflected and so will not enter the fibre. On the other hand photons travelling on a path that is at an angle less than the critical angle will enter the fibre. Once inside a wavelength-shifting optical fibre, some of the photons may be absorbed and re-emitted primarily at a longer wavelength, λ_1. (This shift from an incoming wavelength, λ_0, to a longer, re-emitted wavelength, λ_1, is the source of the name "wavelength-shifting fibre".)

[0007] Re-emission within the fibre at λ_1, is also isotropic, and so it results in a change of direction of the photon. Most of the re-emitted photons escape, passing through the wall of the optical fibre. Only those photons that happen to be re-emitted at a sufficiently acute angle with respect to the axis of the fibre will undergo total internal reflection so as to be transmitted the length of the fibre to the PMT or other photosensor at the fibre's end. The rest of the re-emitted photons pass through the walls of the fibre and never reach the photosensor at the end of the fibre.

[0008] Because of various well known physical factors, the overall efficiency (ε) of delivering photons to the ends of the fibre is limited for this system, typically approaching 8% ($\varepsilon \leq 0.08$). The remaining 92% of the re-emitted photons escape and go undetected. This inefficiency is a major factor limiting spatial and energy resolution of a detector using wavelength-shifting optical fibres. The statistical limit of spatial resolution (Δx) of the detector is inversely proportional to the square root of the number of photons available to be trapped multiplied by the trapping efficiency. Mathematically this may be expressed as:

$$\Delta x \propto 1/(\varepsilon N)^{½}$$

where N is the number of photons emitted by the crystal and e is the capturing efficiency. Similarly the energy resolution ($\Delta E/E$) of a detector is inversely proportional to the square root of the number of photons available to be trapped multiplied by the trapping efficiency. Mathematically this may be expressed as:

$$\Delta E/E \propto 1/(\varepsilon N)^{½}$$

[0009] Another factor which affects the efficiency of the absorption process is the bandwidth of the light sur-

rounding λ_0 and λ_1. Neither of these two wavelengths is a single value. Instead, the photons emitted by the scintillating crystal and the photons re-emitted by the wavelength-shifting optical fibre have a range of wavelengths centred about these values. Indeed, this is true of all the wavelengths discussed in this specification.

[0010] As noted above, λ_0 is a characteristic of the scintillating crystal related to the atomic structure of the chemicals composing the crystal. Similarly, the wavelength at which the wavelength-shifting optical fibre absorbs, λ_0, and its re-emission wavelength, λ_1, are characteristics of the wavelength-shifting optical fibre. Specifically, the change in wavelength (λ_1-λ_0) in a wavelength-shifting optical fibre is influenced by a dopant in the fibre. Different dopants cause the fibre to absorb photons of different wavelengths and re-emit at other characteristic wavelengths. Suitable dopants include but are not limited to bis-MSB which has an absorption peak at 345 nm and an emission peak at 420 nm (blue) and the fluor K-27 which has an absorption peak at 427 nm and an emission peak at 496 nm (green). Suitable wavelength-shifting fibres can be purchased from Bicron Corporation in Newbury Ohio and Kuraray Corp. of Japan.

[0011] Because of the bandwidths associated with each of the various wavelengths, it is important to select a wavelength-shifting optical fibre with characteristics that allow it to absorb the visible photons from the scintillating crystal and re-emit photons at a longer wavelength, and it is important that the bandwidths of the absorption and re-emission do not overlap substantially. The reason for this is clear. If the wavelength-shifting optical fibre happens to emit a photon at the high (short) end of its re-emission bandwidth, λ_0-$\Delta\lambda$=λ_3 and λ_3 happens to be within the bandwidth that the wavelength-shifting optical fibre will absorb, that photon can be re-absorbed by the optical fibre. If this occurs, that particular photon has only a very small chance of being conducted by the fibre to its end for detection. Accordingly, where there is substantial overlap between the absorption and re-emission wavelengths of the wavelength-shifting optical fibre, the efficiency, e, decreases and the quality of the resulting image is degraded.

[0012] The present invention includes a scintillation or emission detector comprising wavelength-shifting optical fibres which are selected and arranged to capture a greater percentage of visible photons than has been done heretofore. This is accomplished through the use of two or more different colour stages of wavelength-shifting fibres. A primary set of optical fibres contains a first wavelength-shifting optical fibre tuned to absorb photons emitted by a scintillator and to re-emit photons at a longer wavelength. At least some of the re-emitted photons from the primary set of optical fibres are captured and transmitted down the first wavelength-shifting optical fibre. A secondary set of optical fibres contains a second wavelength-shifting optical fibre tuned to absorb photons emitted by the primary set of optical fibres and to re-emit photons at a still lower frequency. In this way at least some of the photons emitted by the primary set of optical fibres and not transmitted down the first optical fibre are captured and transmitted down the secondary optical fibre. This improves the spatial and energy resolution of the detector by capturing and detecting some of the photons that have heretofore escaped undetected and therefore have not contributed to the resulting image. An electro-optical device is positioned to detect photons received from at least one end of the first or second wavelength-shifting optical fibres and to generate an electrical signal in response.

[0013] In one aspect of the present invention, the radiation detector further includes at least one tertiary set of optical fibres tuned to absorb photons emitted by the secondary set of optical fibres and not internally reflected by them. The tertiary set of fibres absorbs incident photons which escaped the secondary fibres. These photons are re-emitted isotropically and at a longer wavelength, and at least some of them will be internally reflected and so reach a photon detector at the end of the tertiary fibre.

[0014] In another aspect, the invention provides a camera using a detector of the kind referred to.

[0015] In the context of the specification which follows, it is convenient to speak of the wavelength-shifting optical fibres as being grouped in bundles, each bundle including two or more different colour stages of wavelength-shifting optical fibres, each tuned to absorb some of the photons which escape from the preceding stage and to propagate photons at a longer wavelength. The fibres of each bundle may all have one end connected to a single photodetector, with the opposite ends mirrored, or each fibre may have its own photodetector. Alternatively, one or more photon detectors may be used at each end of each bundle. The optimal association of fibres to photosensors depends on many factors, for example, cost, degree of multiplexing, bandwidth of the photosensors, and the effect of coarse spatial sampling on the spatial resolution.

[0016] Ways of carrying out the invention will now be described in detail, by way of example, with reference to the accompanying drawings, in which:

Figure 1 is a perspective illustration of a gamma camera including a detector mounted on a track to move about a patient;

Figure 2 is a schematic perspective illustration of a detector head suitable for use in the device of Figure 1 and having orthogonal bundles of optical fibres on opposite sides of a scintillating crystal;

Figure 3 is an illustration of an end portion of a bundle of optical fibres all of which are connected to a single photomultiplier tube suitable for use in the detector of Figure 2;

Figure 4 illustrates a bundle of optical fibres with a photomultiplier tube at each end and suitable for use in the detector of Figure 2;

Figure 5 is an enlarged, cross sectional view of a scintillating crystal and a pair of optical fibres showing possible events when a gamma ray interacts with the crystal;

Figure 6 is a cross sectional view of a portion of the detector of Figure 5 showing part of the scintillating crystal and an arrangement of optical fibres;

Figure 7 is a view similar to Figure 6 but showing another arrangement of optical fibres suitable for use in the present invention;

Figure 8 is a view similar to Figure 6 but showing yet another arrangement of optical fibres suitable for use in the present invention;

Figure 9 is a perspective illustration of a bundle of optical fibres connected to a photodetector for use in practising the present invention in which one of the fibres includes a scintillating material, the bundle of fibres being provided with a photon detector at one end of the fibres;

Figure 10 is a schematic, perspective illustration of a detector formed of the bundles of Figure 9; and

Figure 11 is a perspective illustration of a bundle of optical fibres like that shown in Figure 9, but in which each fibre is provided with a separate photon detector.

[0017] The present invention provides a detector 8 for detecting gamma rays and suitable for use in a radiation detecting camera 10 illustrated schematically in Figure 1. The detector 8 (Figure 2) includes a scintillation crystal 12 which is formed of a radiation sensitive material such as YAP:Ce. (cerium doped yttrium aluminium perovskite), or another conventional material. This material scintillates when hit by a gamma ray, and the emitted photons are in the ultraviolet range of the electromagnetic spectrum at about 347 nm. Other suitable scintillating materials include but are not limited to crystals of BGO (bismuth germanate ($Bi_4Ge_3O_{12}$), NaI(T1) (sodium iodide doped with thallium), and CsI(Na) (cesium iodide doped with sodium).

[0018] The crystal 12 (Figure 2) is generally in the form of a rectangular solid. For example the crystal may be between one quarter (1/4) inch (0.64 cm) and three quarters (3/4) inches (1.91 cm) thick and about nineteen (19) inches (48.26 cm) wide by twenty-four (24) inches (60.96 cm) long. One of the major side surfaces of the crystal 12 is covered with a plurality of bundles 14 of optical fibres which extend parallel to each other and to one pair of opposite edges of the crystal. The opposite major side surface of the crystal 12 is covered with a plurality of bundles 16 of optical fibres that extend parallel to the other pair of opposite edges of the crystal. When viewed along a line normal to the major side surfaces of the crystal 12, the bundles 14 and 16 of optical fibres on the two sides form an orthogonal grid, and any point in the crystal can be defined by its position relative to the fibres in this grid.

[0019] Each of the plurality of fibre bundles 14 and 16 are identical and only the representative bundle 14 will be described in detail, it being understood that the description applies as well to the bundles 16. In one embodiment, each optical fibre bundle 14 is connected to a photon detecting device such as a photomultiplier tube (PMT) 18 (Figure 3), the output of which may be processed in a conventional manner to recreate an image of the source of the incident gamma rays. The bundle 14 may be connected to a PMT 18 at one end (Figure 3), or separate PMTs 18 and 18' may be provided at each end of the bundle (Figure 4). In the former case the end of the bundle 14 that does not have a PMT may be provided with a mirror (not shown), so that photons initially travelling away from the PMT are reflected and eventually counted.

[0020] Instead of photomultiplier tubes 18 and 18', avalanche photodiodes can be used, or hybrid PMTs which have a photocathode with a silicon photodiode at high voltage may be used. Visible light photon counters (VLPCs) can also be used. It is likely that such detectors will be improved over the coming years and others discovered or made economical. It will be understood by those skilled in the art that PMT 18 is exemplary and that the key feature for the photon detector is simply that it reliably count the photons which arrive from the fibres.

[0021] In any case, when a gamma ray 40 (Figure 5) strikes the crystal 12, a flash of light consisting of many photons having a wavelength (λ_0) of about 347 nm are emitted. One such photon 42 is illustrated in Figure 5. Photons like photon 42 travel through the crystal 12 in many directions, with some going toward one major side surface, and many others going in other directions. A few of these (including the exemplary photon 42) will be wave-shifted and re-emitted axially by the fibre bundles 14 and 16 (Figure 2), and ultimately the event will be recorded by the PMT 18 or other photon detecting device.

[0022] The bundle 14 (Figure 3) is formed of a group of fibres such as fibres 50, 52, 54, and 56. Fibres 50 and 52 are identical and each is tuned by means of its chemical composition to absorb ultraviolet light at about 345 nm (λ_0). Once the fibre 50 (or 52) absorbs the incident ultraviolet radiation, it re-emits photons of a longer wavelength (λ_1), such as, for example blue light. This re-emission is isotropic, and accordingly, some of the blue photons, for example photon 60 in Figure 5, are travelling in a direction sufficiently close to parallel to the axis of the fibre 50 to undergo total internal reflection.

In Figure 5, the critical angles for total internal reflection are shown for purposes of illustration as angles 62 and 64 for the fibres 50 and 54, respectively. A photon travelling within the critical angle 62 eventually arrives at the PMT 18 (Figure 3), and this in turn, generates an electrical signal to indicate that a pulse has been received.

[0023] By way of example, the fibre 50 (Figure 5) may be a conventional plastic optical fibre having a polystyrene core 70 clad with a layer 72 of PMMA and doped with the fluor bis-MSB. This dopant has an absorption peak at 345 nm (ultraviolet) and an emission peak at 420 nm (blue). Its absorption peak fits well with the emission peak of the crystal 12 which occurs at 347 nm. Other suitable fibres may be formed of plastic, glass or liquid filled glass capillaries, and other sequences of dopants may be used, as will be apparent to those skilled in the art from the following specification.

[0024] The bundle 14 also includes optical fibre 54 (Figures 3 and 5). The fibre 54 is located adjacent to fibre 50 and extends generally parallel to it. The fibre 54 has different optical properties from those of fibre 50. While the fibre 50 absorbed in the ultraviolet (λ_0) and emitted in the blue (λ_1), effectively shifting the wavelength of the incoming photons to a longer wavelength, the adjacent fibre 54 absorbs photons in the blue portion of the visible spectrum ($\approx\lambda_1$) and re-emits at a longer wavelength (λ_2), such as the green portion of the visible spectrum. Most of the photons emitted in the blue range by the fibre 50 pass through the walls of that fibre since they are not within the critical angle 62. These, like photon 76, escape the fibre 50 and have a chance of interacting with the secondary fibre 54.

[0025] The secondary fibre 54 is tuned by the addition of appropriate dopants to absorb most strongly photons of about the same wavelength as are emitted by the primary fibre 50. For example, the secondary fibre 54 may be the same as the conventional fibres described above but doped with K-27. This dopant has an absorption peak at 427 nm (blue) and an emission peak at 496 nm (green). As a result, some of the (blue) photons (λ_1) that were not internally reflected by the primary fibre 50 are captured by the secondary fibre 54. One such photon is shown as photon 76 in Figure 5. Secondary fibre 54 absorbs photon 76 and re-emits a photon at a longer wavelength (λ_2), for example in the green portion of the visible spectrum. As with the primary fibre 50, the re-emission of the secondary fibre 54 is isotropic, and some of the re-emitted photons, such as photon 78, are travelling in a direction that causes them to be totally internally reflected, and so to reach the PMT 18.

[0026] Accordingly, the bundle 14 includes at least two wavelength-shifting optical fibres 50 and 54. The primary fibre 50 shifts the incident light from λ_0 to λ_1 and the secondary fibre 54 shifts light from λ_1 to λ_2. The secondary wavelength-shifting optical fibre 54 is set along side the primary fibre 50 and receives re-emitted visible photons that escape detection by the primary fibre because the direction in which they were emitted does not permit them to be internally reflected and conducted down the fibre 50 to a detection device such as the PMT 18.

[0027] The bundle 14 may also include a third fibre 56 (Figure 3). This fibre is adjacent to the fibre 54. In the arrangement shown in Figure 3, two fibres 50 and 52 with an output in the blue portion of the visible spectrum are side by side. These fibres are placed closest to the crystal 12 as shown in Figure 6. The fibres 54 and 56 are placed directly above the fibres 50 and 52, respectively, as shown in Figures 3 and 5. Figure 5 shows two bundles 14 placed side by side on the crystal 12.

[0028] The fibre 54 is similar to the other three, but contains a dopant that causes it to absorb most strongly at the wavelength emitted by fibre 54 (λ_2) and to re-emit at an even longer wavelength, λ_3, for example, the orange region of the visible spectrum. Some of those orange photons would reach the PMT 18 (Figure 3) through total internal reflection.

[0029] Alternative arrangements and fibre selections are also possible. For example, the fibre 56 could be identical to the fibre 54, or all four of the fibres could be different, each tuned to absorb most strongly at a wavelength at or close to that at which another of the fibres emits. In addition the arrangement of the fibres can be varied. For example, the fibres do not need to be stacked directly over one another as shown in Figure 6. Instead they could be offset by one fibre radius as shown in Figure 7 which illustrates two such bundles 14' side by side. This arrangement allows for a denser packing of the fibres. Further, the fibres could be arranged three deep as shown in Figure 8. In this arrangement, the fibre bundle 14" (Figure 8) comprises three fibres 50, 54, and 56, each absorbing a portion of the re-emitted photons that escaped the fibre below.

[0030] The invention has been described in connection with a crystal 12 (Figure 2) which emits ultraviolet photons when struck by a gamma ray. These photons are in turn detected by photon detectors 18 connected to the bundles of fibres 14 and 16. It is also possible to combine the functions of the crystal 12 and primary fibre 50. In this case, the primary fibre 100 (Figure 9) is doped with a fluor that emits ultraviolet photons when struck by a gamma ray. The fibre 100 also includes a fluor that absorbs at the ultraviolet and emits at the blue range. (This fluor is often used in scintillating fibres to avoid optical absorption of ultraviolet photons by the fibre core material, typically polystyrene.) In such a case, the crystal 12 is eliminated, and the detector 8' (Figure 10) becomes just a pair of mats of orthogonally arranged bundles 14"' end 16"' of fibres with appropriate photomultiplier tubes.

[0031] As with the embodiments described in connection with Figures 6, 7, and 8, there are various arrangements of fibres possible when using the scintillating fibre 100. One such arrangement is illustrated in Figure 9 where the fibre 100 is surrounded by four additional fibres, 102, 104, 106, and 108. The fibres 102 and 108

may be the same as the fibre 54 of Figure 3. The fibres 102 and 108 may be tuned to absorb most strongly at the wavelength at which the fibre 100 emits, for example absorbing blue and re-emitting green. The fibres 104 and 106 may be like the fibre 56 of Figure 3, absorbing most strongly in the green range and re-emitting in the orange range of wavelengths, for example. Of course other selections are possible, including selecting all four fibres 102, 104, 106, and 108 to be the same as fibre 54. This choice would collect more of the photons that escape from the primary fibre 100, but would not collect any of the photons that escape from the secondary fibres.

[0032] As shown in Figure 9, the primary fibre, the scintillating fibre 100, is about twice the diameter of the surrounding fibres 102 - 108. This is a matter of design choice, and the primary fibre could be larger or smaller. The guiding factors include the need to provide a suitable amount of scintillating material, the stiffness of the resulting fibre (and hence its ease of installation and use), the number of photosensors needed, and the resolution of image required. It is contemplated that a scintillating fibre 100 with about a 1 to 2 mm diameter could be used with surrounding fibres of about 0.5 mm diameter.

[0033] In addition, all of the embodiments of the invention shown and described above include a single photosensor such as the PMT 18 which receives photons from all the fibres of a bundle 14. It is contemplated that separate photodetectors could be used for each fibre of a bundle, and Figure 11 illustrates this by way of example as applied to a bundle of fibres like those shown in Figure 9. In Figure 11 the scintillating fibre 110 is connected to a PMT 112, while the surrounding fibres 114, 116, 118, and 120 are each connected to a separate PMT. 122, 124, 126, and 128, respectively.

[0034] Regardless of whether the scintillating crystal is a large solid as shown in Figure 2 or its functions are performed by a fluor in the primary fibre 100 as shown in Figure 9. the resulting detectors 8 and 8' (Figures 2 and 10) and camera 10 using such detectors have improved spatial and energy resolution because more photons are captured.

[0035] Although the invention has been shown and described with respect to several preferred embodiments, it will be apparent that equivalent alterations and modifications will occur to others skilled in the art upon the reading and understanding of this specification. The present invention includes all such equivalent alterations and modifications, and is limited only by the scope of the following claims.

Claims

1. A scintillation detector comprising: first and second wavelength-shifting optical fibres, the first fibre (50, 52, 100) absorbing photons at a primary wavelength and re-emitting photons at a secondary wavelength, the secondary wavelength being longer than the first wavelength, the second fibre (54, 102, 108) absorbing photons at the secondary wavelength and re-emitting photons at a tertiary wavelength, the two fibres being located in close physical proximity so that at least a portion of the photons escaping from the first fibre at the secondary wavelength are absorbed by the second fibre.

2. A detector as claimed in claim 1, further including a third wavelength-shifting optical fibre (56, 104, 106) absorbing photons at the tertiary wavelength and re-emitting photons at a quaternary wavelength, the third fibre being located in close physical proximity to the second fibre (54, 102, 108) so that at least a portion of the photons escaping from the second fibre at the tertiary wavelength are absorbed by the third fibre.

3. A detector as claimed in claim 1 or claim 2, including a plurality of said first fibres and a plurality of said second fibres, the first and second fibres being grouped into a plurality of bundles (14, 16), each bundle including at least one first fibre and one second fibre.

4. A detector as claimed in claim 3, wherein the bundles are arranged in two groups with the bundles (14) in one group extending transverse to the bundles (16) in the other

5. A detector as claimed in claim 4, wherein the groups of fibres extending transverse to each other form a grid.

6. A detector as claimed in any one of claims 1 to 5, wherein the first wavelength-shifting optical fibre is a scintillating fibre (100).

7. A detector as claimed in claim 6, further including a plurality of second fibres (102, 104, 106, 108) disposed about each first fibre (100).

8. A detector as claimed in any one of claims 1 to 7, wherein the first and second fibres are connected to a single detection unit (18, 18') for detecting photons in the first and second fibres.

9. A detector as claimed in any one of claims 1 to 7, wherein each of the first and each of the second fibres is connected to its own detection unit (122, 124, 126, 128) for detecting photons in the respective fibre.

10. A detector as claimed in any one of claims 1 to 9, further including radiation sensitive material (12, 100) which emits photons upon stimulation by radi-

ation and an electro-optical device (18, 18', 122, 124, 126, 128) positioned to detect photons received from at least one of the first and second fibres to generate a signal in response thereto.

11. A detector as claimed in claim 10, wherein the electro-optical device is a photomultiplier tube or a photodiode.

12. A detector as claimed in claim 10 or claim 11, wherein the first wavelength-shifting optical fibres is disposed in a row and the second wavelength-shifting optical fibres is disposed in a row, the row of first wavelength-shifting optical fibres being disposed between a surface of the radiation sensitive material and the row of second wavelength-shifting optical fibres.

13. A detector as claimed in any one of claims 10 to 12, wherein the radiation sensitive material (12) is an inorganic crystalline material, and the first wavelength-shifting optical fibre is positioned in close proximity to the radiation sensitive material.

14. A detector as claimed in any one of claims 1 to 13, wherein the radiation sensitive material is a fluor within the first wavelength-shifting optical fibre (100).

15. A method of detecting radiation, comprising the steps of: positioning a scintillator (12, 100) to receive radiation; absorbing photons of a first wavelength emitted from the scintillator in a plurality of wavelength-shifting first optical fibres (50, 52, 100); absorbing photons of a second wavelength which is longer than the first wavelength in a plurality of wavelength-shifting second optical fibres (54, 102, 108); and propagating photons through the first and second optical fibres to a photodetector (18, 18', 122, 124, 126, 128) in response to the absorption of photons by the optical fibres.

16. A method of detecting radiation as claimed in claim 15, in which the radiation is gamma rays.

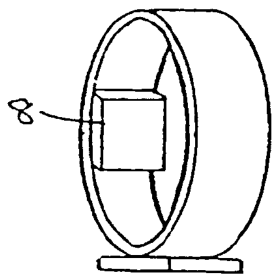

FIG.1

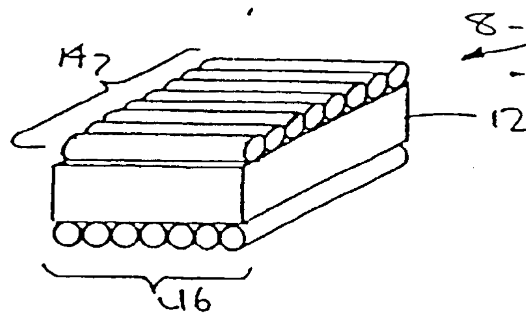

FIG. 2

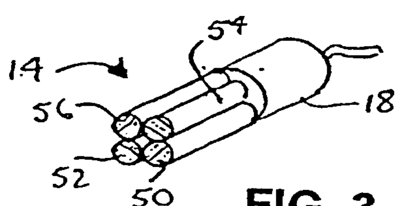

FIG. 3

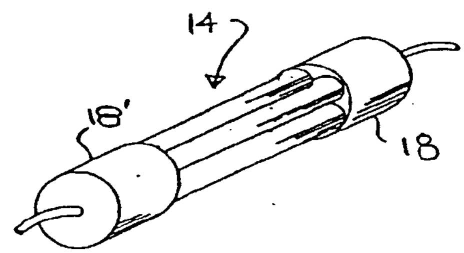

FIG. 4

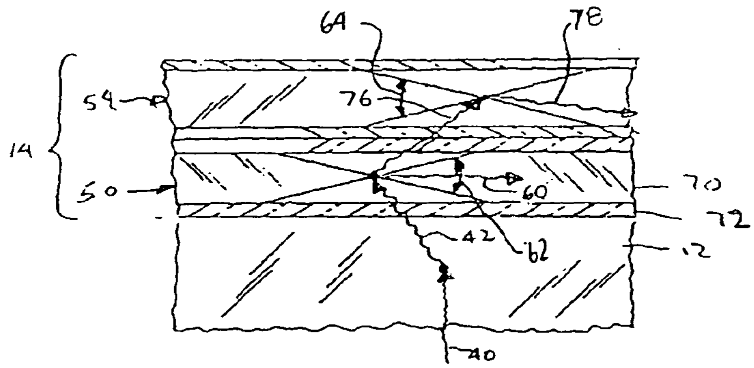

FIG. 5

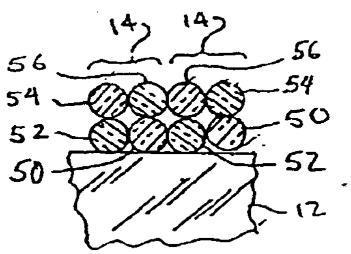

FIG. 6

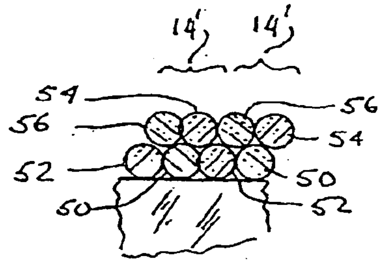

FIG. 7

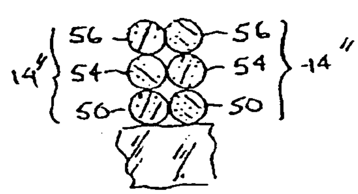

FIG. 8

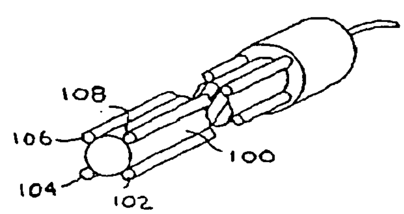

FIG. 9

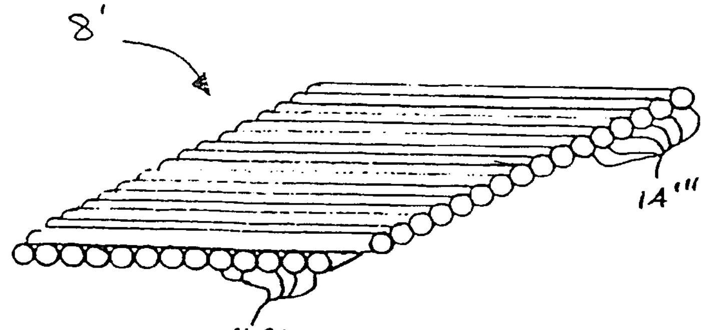

FIG. 10

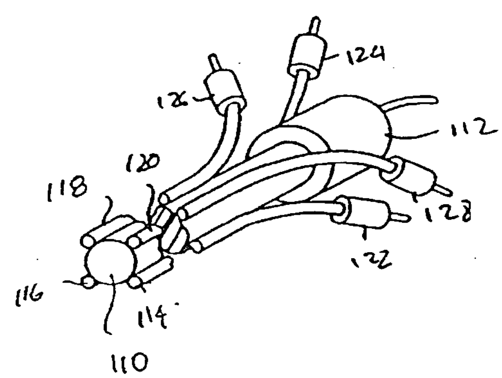

FIG. 11

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